

Verification Testing with Installation and Developmental Assessment Problems

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Outline

- Background
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Background

- Recent code development tasks have expanded requirements for testing of proposed code modifications
 - The “Improved Accuracy for Two-Phase Downflow Scenarios” was the first task with the expanded requirements
 - It will be used to demonstrate the methods that were developed
 - The methods developed for this task are expected to be used for subsequent tasks
- The testing is desired to be more extensive, systematic, and rigorous than done in the past

Background

- More extensive:
 - Includes applicable test problems, installation problems, and developmental assessment (DA) cases
 - Includes testing of four time step options ($tt = 3, 7, 11, \text{ and } 15$)
 - Includes both LINUX and Windows operating systems
- More systematic:
 - Previous testing of installation problems focused on successful execution
 - LINUX diff commands were used to identify which problems had changed
 - The diff results were not very useful when the code modifications were expected to change the results
- More rigorous:
 - There generally was not a record of results

Method

- Develop processes that automatically generate plots that compare important results with four time step options
- Develop processes that will automatically generate plots that compare important results between two codes with one time step option
- Develop subjective measures for acceptability
- Document results
 - Identify significant differences due to code modifications
 - Identify cases where the variability in results indicates increased levels of numerical uncertainty
 - Identify cases where there appears to be an error associated with one of the time step options
 - Identify potential improvements in test cases

Method for Installation Problems

- Each base input file in the *run*, *run/Athena*, and *run/Other* directories was reviewed to determine what the problem was designed to test
- Important parameters that could be plotted were identified for each problem
- A table that describes each installation problem and identifies the important parameters was created

Base input file	Description	Plot parameters
run directory		
ans79.i ¹	Uses the 1979 ANS decay heat standard in a steady-state power calculation	rkgapow-0, rkacpow-0
ans94.i ¹	Uses the 1994 ANS decay heat standard in a steady-state power calculation	rkgapow-0, rkacpow-0
ans05.i ¹	Uses the 2005 ANS decay heat standard in a steady-state power calculation	rkgapow-0, rkacpow-0
cstest1.i	Tests a steady-state control system for a simple PWR model	pmpvel-170, mflowj-201000000, mflowj-231000000, cntrlvar-12, cntrlvar-20

Method for Installation Problems

- AptPlot scripts were written that plot the important parameters for each installation problem (*file.i*)
 - *file.apl* plots results from one code with four tt options
 - *file_comp.apl* plots results from two codes with tt = 3
- A FORTRAN program (*readtt.f*) was written that reads a RELAP5-3D input file and changes the tt option on the time step cards to either 3, 7, 11, or 15
 - The program also revises the 104 card, if present, so that restart and plot files are saved
 - Accounts for steady-state convergence checking (tt=16)
- LINUX scripts were created that use *readtt.x* to make four copies of each input file, with tt specified as 3, 7, 11, or 15
- LINUX scripts were created to run four cases for each installation problem and make comparison plots using the AptPlot scripts
- Comparable *make* files were created for Windows

Method for Installation Problems

- Qualitative criteria were developed to judge differences due to time step options
 - A. The comparison plots indicate that the four time step options appear to produce identical results for all important parameters. The comparison plots do not reveal any potential numerical problems.
 - B. The comparison plots indicate that the four time step options produce slightly different results. Although the differences between options are noticeable, they are judged to be small and relatively insignificant. The comparison plots do not reveal any potential numerical problems.
 - C. The comparison plots indicate that the four time step options produce differences that are larger than small, but are not necessarily unexpected. The differences do not indicate problems or errors associated with any of the time step options, but do indicate that the calculated results are somewhat sensitive to the choice of time step controls. Therefore, the numerical uncertainty in the calculation is judged to be potentially significant.
 - D. The comparison plots indicate a significant problem or error associated with at least one of the time step options. The user must take care in the selection of time step option in order to obtain reasonable results.

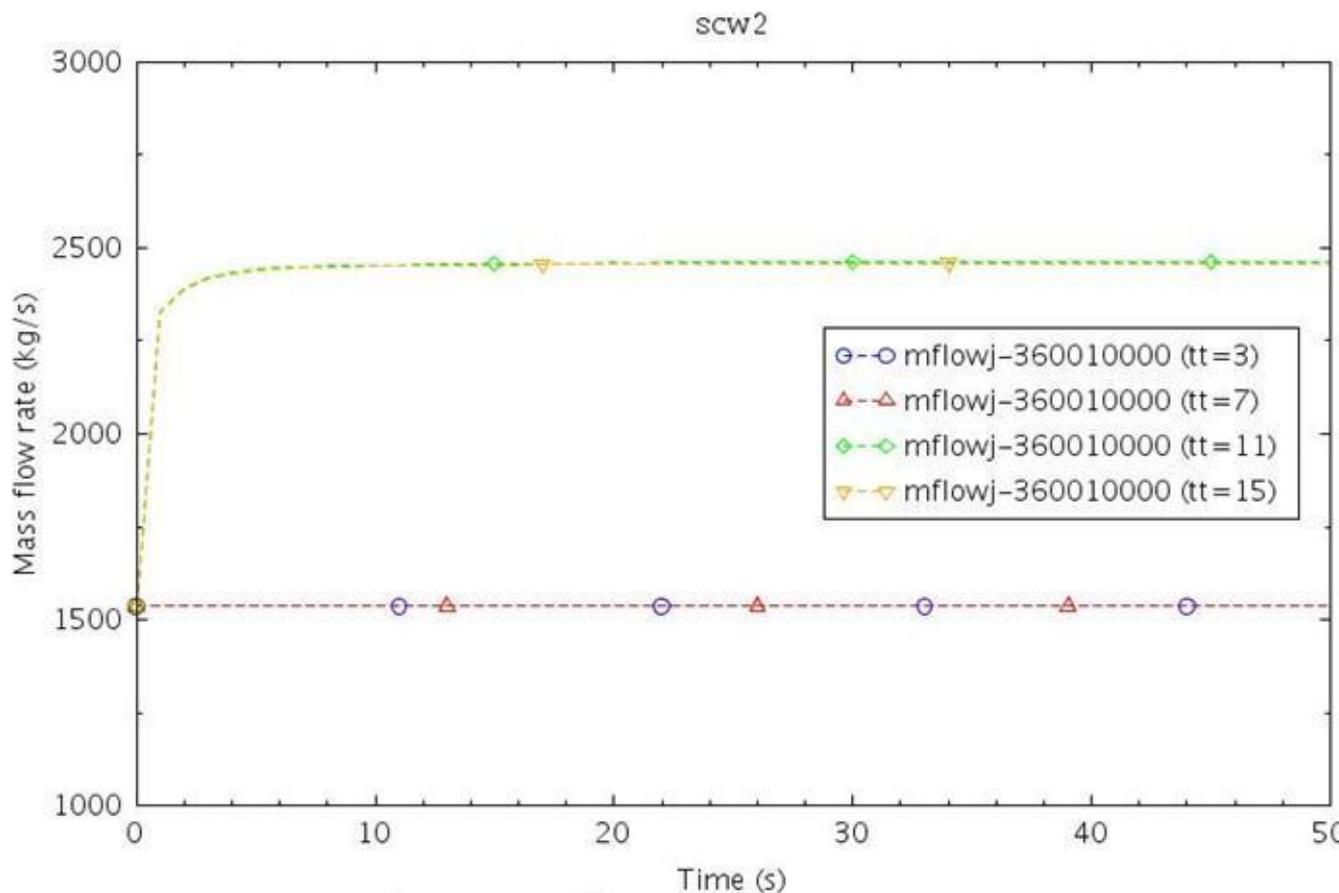
Results for Installation Problems

- Qualitative judgments were made on the effects of time step options for two code versions for each installation problem
 - RELAP5-3D Version 3.0.2t
 - RELAP5-3D Version 3.0.2.t + modifications for very high downflow
- The four tt options produced identical or similar results for all of the installations problems with both the original and modified codes except for those shown on the next slide
 - Subsequent figures were generated with the modified code

Installation Problems with Significant Variations (*LINUX*)

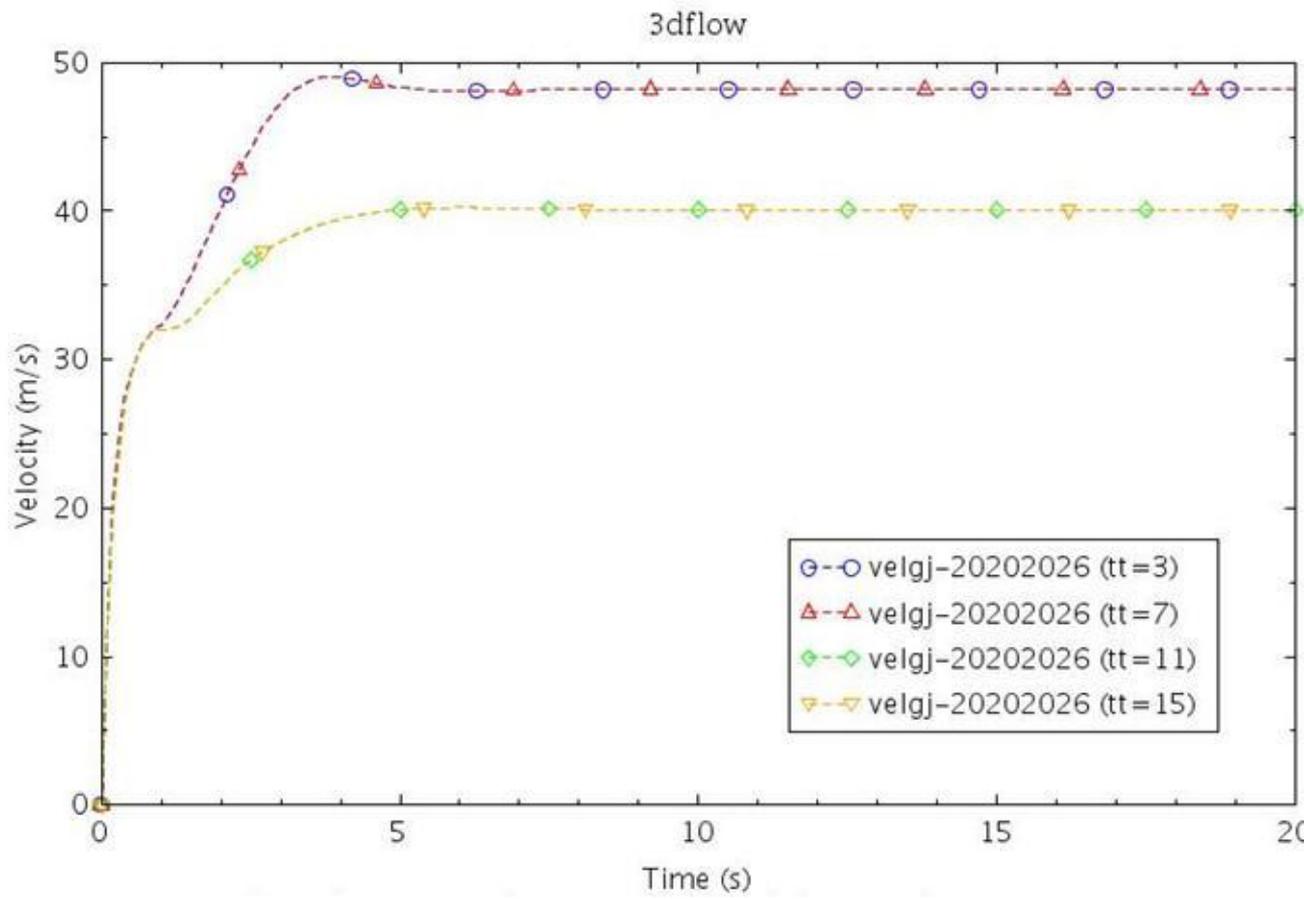
Base input file	Qual. judgment		Comments
	Original	Modified	
jetpmp.i	D	D	Mass flow rates vary significantly at times between the semi-implicit and nearly implicit schemes
pois_cyl_he.i	D	D	Problem fails with the nearly implicit numerical scheme
sschf2.i	C	C	Transient wall temperature response near the beginning of the film boiling region varies significantly between the semi- and nearly implicit schemes
scw.i, scw2.i	D	D	Nearly implicit scheme results in excessive mass error and is not recommended for applications with supercritical water
turbine9.i	D	D	Turbine performance varies significantly between the semi- and nearly implicit schemes
typ12002.i	C	C	Detailed response varies considerably following loop seal clearing, but conclusions regarding safety parameters are not affected
3dflow.i	D	D	Significant difference in steady axial fluid velocity
cbdbipb.i	D	D	Calculation fails with the nearly implicit scheme
tank.i	D	D	Results much more oscillatory with the nearly implicit scheme

Results for Installation Problems (LINUX)



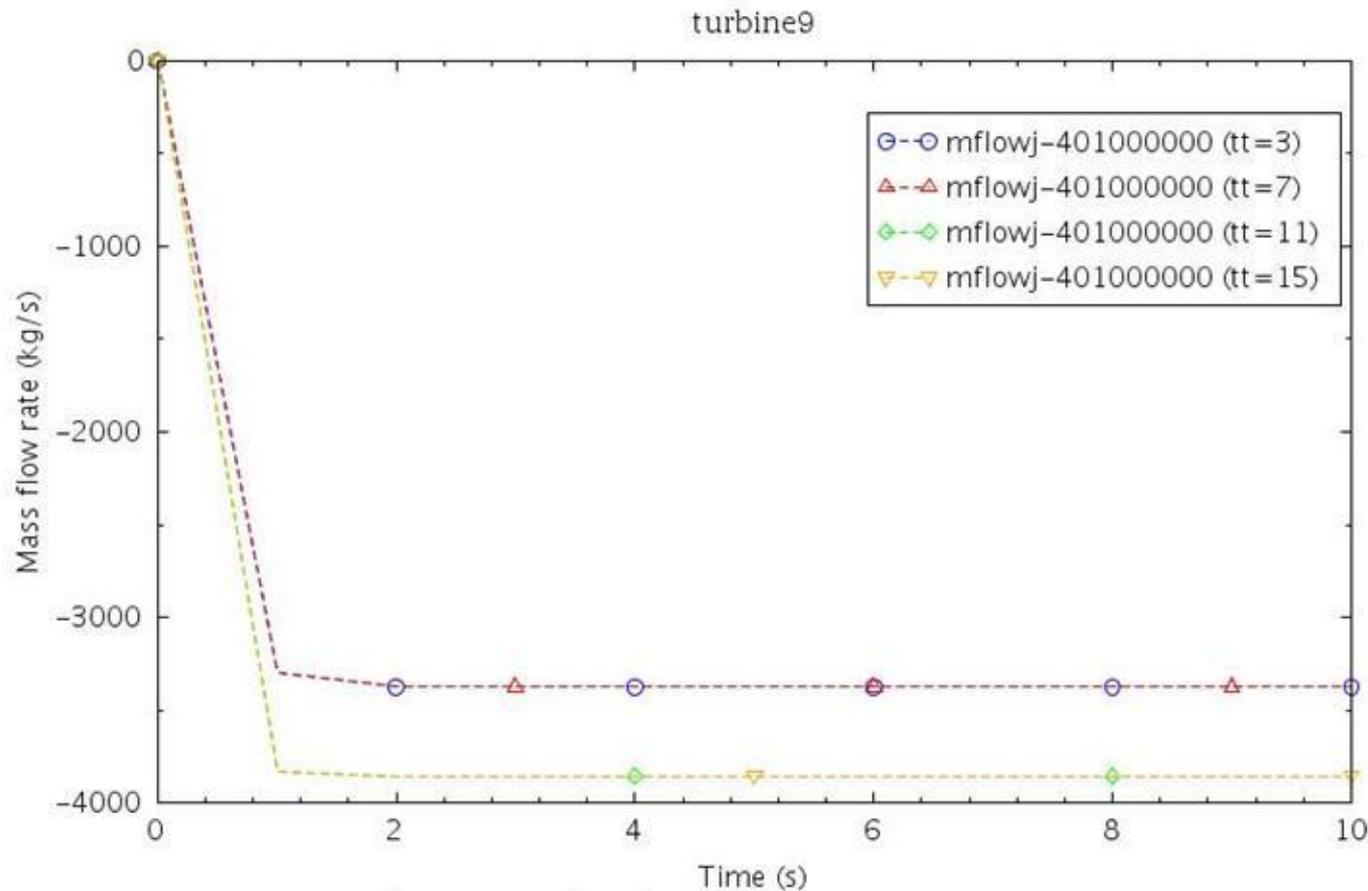
- Steady state in a supercritical water reactor with Option 11
- Mass flow rate in the upper plenum
- Nearly implicit scheme results in excessive mass error when crossing critical temperature at supercritical pressure

Results for Installation Problems (LINUX)



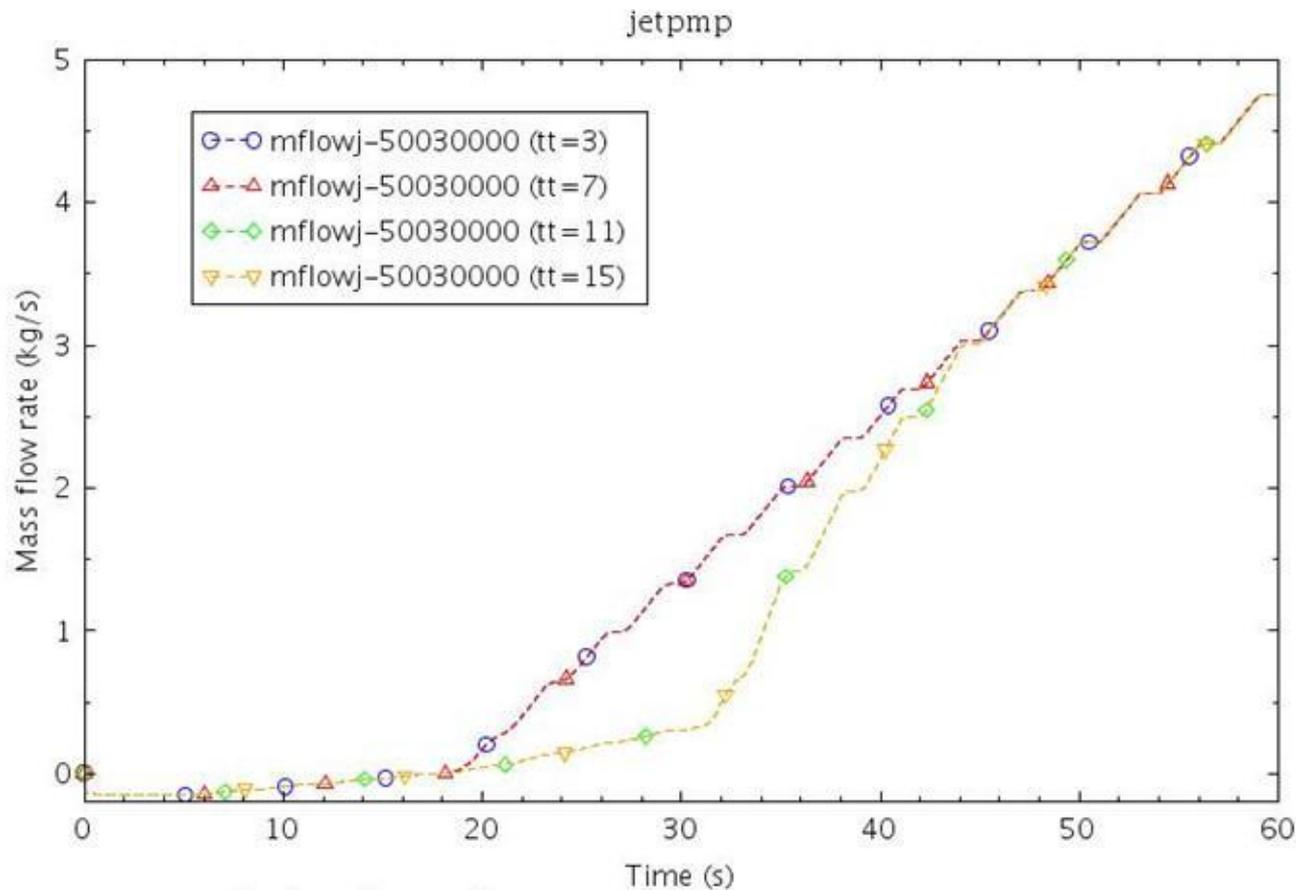
- 3-D, two-phase flow in a 3x3x3 Cartesian grid
- Gas velocity in axial direction near downstream end of duct
- Significant difference between semi- and nearly implicit schemes

Results for Installation Problems (LINUX)



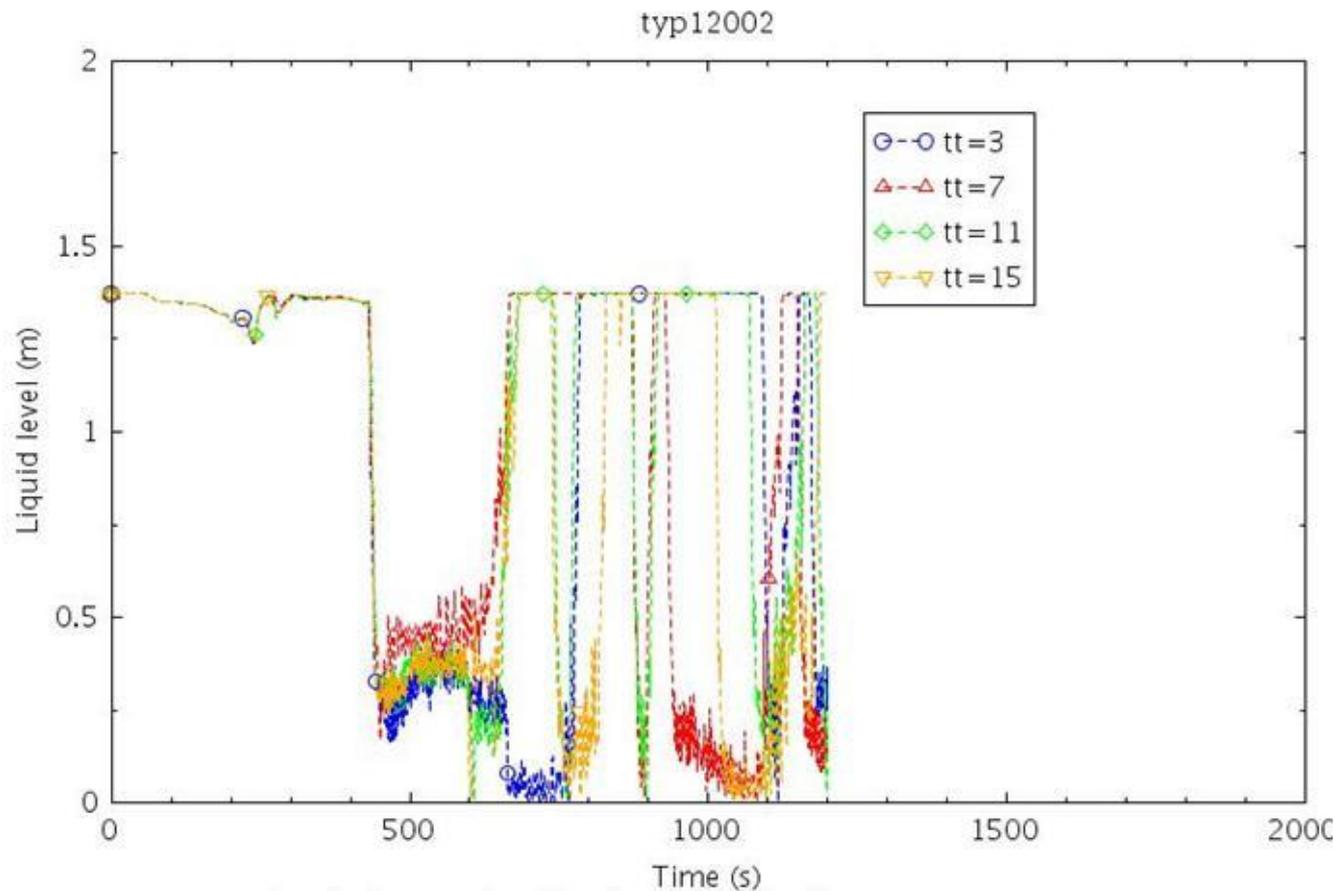
- Multi-stage steam turbine with moisture separation
- Mass flow rate through the turbine
- Significant difference between semi- and nearly implicit schemes

Results for Installation Problems (LINUX)



- Jet pump test case
- Combined drive and suction flow through the jet pump
- Mass flow rate varies significantly at times between the semi- and nearly implicit schemes

Results for Installation Problems (LINUX)



- SBLOCA in a PWR
- Single loop seal upflow leg liquid level
- Differences following loop seal clearing reflect periods of increased numerical uncertainty
- Conclusions regarding safety parameters are not affected

Results for Installation Problems (Windows)

- The testing of time step options on the installation problems was repeated with the Windows operating system
- The base code for the Windows testing was RELAP5-3D Version 3.0.1.t instead of 3.0.2.t, which did not install on Windows systems at the INL at the time the analysis was performed
- The results with the Windows operating system were generally similar to those shown previously

Summary of Testing of Installation Problems

- The original and modified codes behaved similarly
- The nearly implicit scheme caused problems when modeling multi-dimensional, jet pump, and turbine components
- The nearly implicit scheme caused enormous mass error for cases in which the critical temperature was crossed at supercritical pressure
- Increased numerical uncertainty was observed following the clearing of the loop seals in SBLOCA calculations

Method for DA Cases

- The DA cases from Bayless (2011) were repeated with LINUX and Windows operating systems
 - 17 phenomenological cases
 - 27 separate effects tests
 - 8 integral effects tests
- SNAP was used to perform four sensitivity calculations ($tt = 3, 7, 11, 15$) and generate comparison plots for each case
- Comparison plots were reviewed and qualitative judgments made about the variability in results for each case
 - Qualitative judgments used the same criteria as for the installation problems (A, B, C, D)
- The four tt options produced identical or similar results for all of the DA cases except for those shown on the next slide

DA Cases with Significant Variations (LINUX)

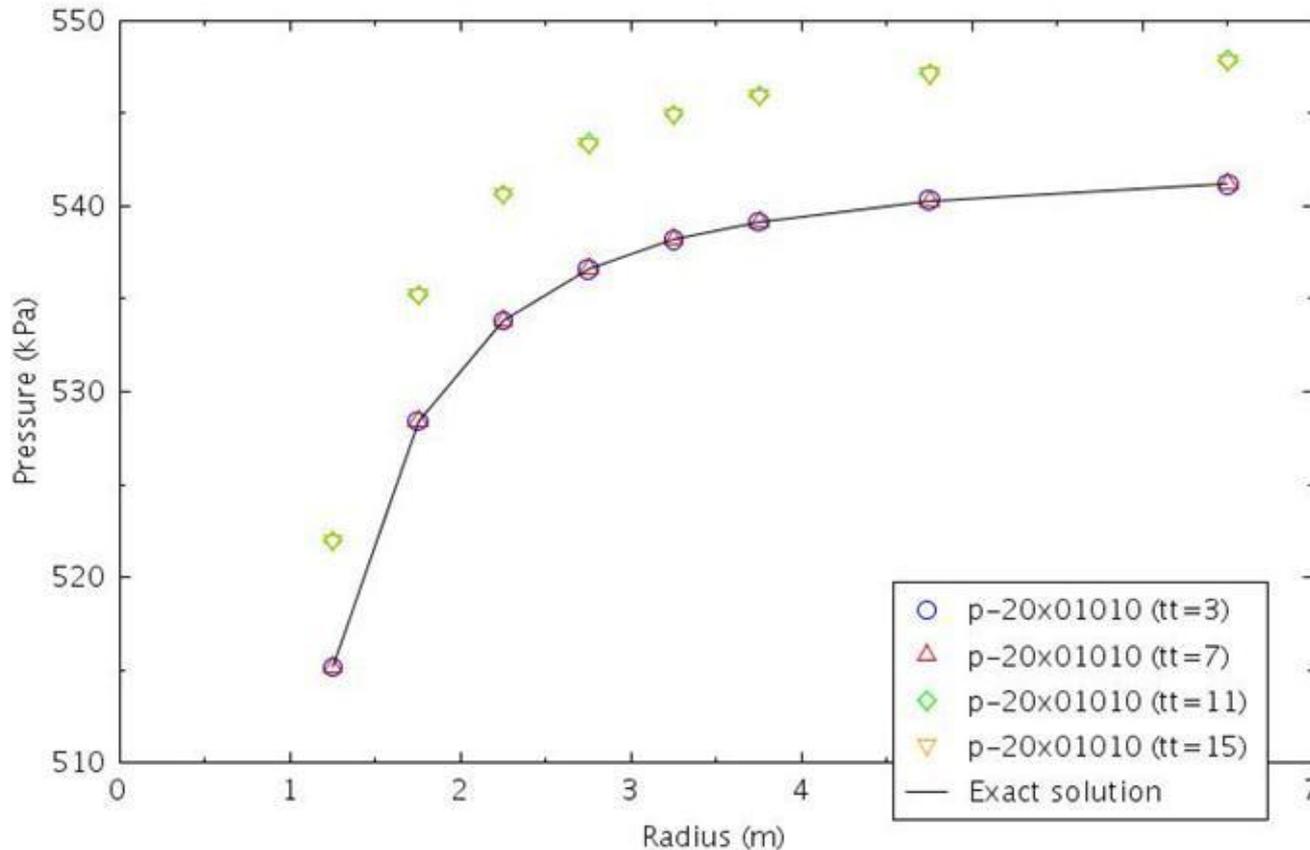
Case	Qualitative judgment
Water over steam (3-D)	D*
Bubbling steam through liquid	D
Manometer	D*
Pryor pressure comparison	C
Rigid body rotation (3-D)	D
R-theta symmetric flow (3-D)	D
FLECHT SEASET Test 31504	C
Semiscale Tests S-NC-1, S-NC-2, S-NC-3, and S-NC-10 Parts 2, 3, and 4	A, B, B, B, C, D*
LOBI Test A1-04R	C
LOFT Experiment L2-5 (1-D)	C
LOFT Experiment L2-5 (3-D)	D*

* Code failed

Results for DA Cases (LINUX)

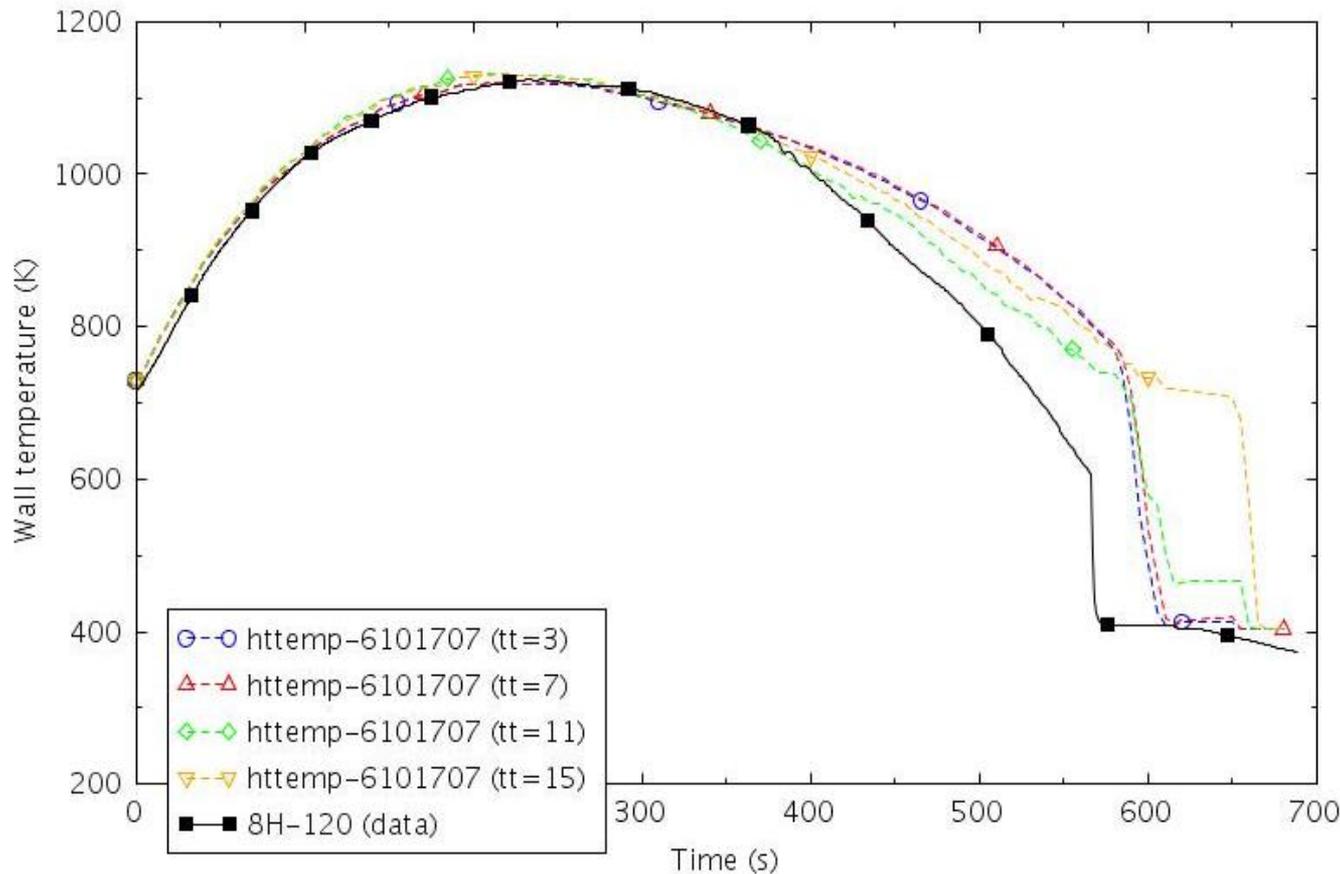
- Code performance was more robust with the semi-implicit numerical scheme
 - Code failures were encountered with the nearly implicit scheme for
 - Water over steam (3-D)
 - Semiscale NC Test 10 Part 4
 - LOFT Experiment L2-5 (3-D)
 - Similar failures were observed with the original code or in previous versions
 - Code failures were encountered in the manometer problem with the level tracking model in both the original and modified codes
 - This problem has been corrected

Results for DA Cases (LINUX)



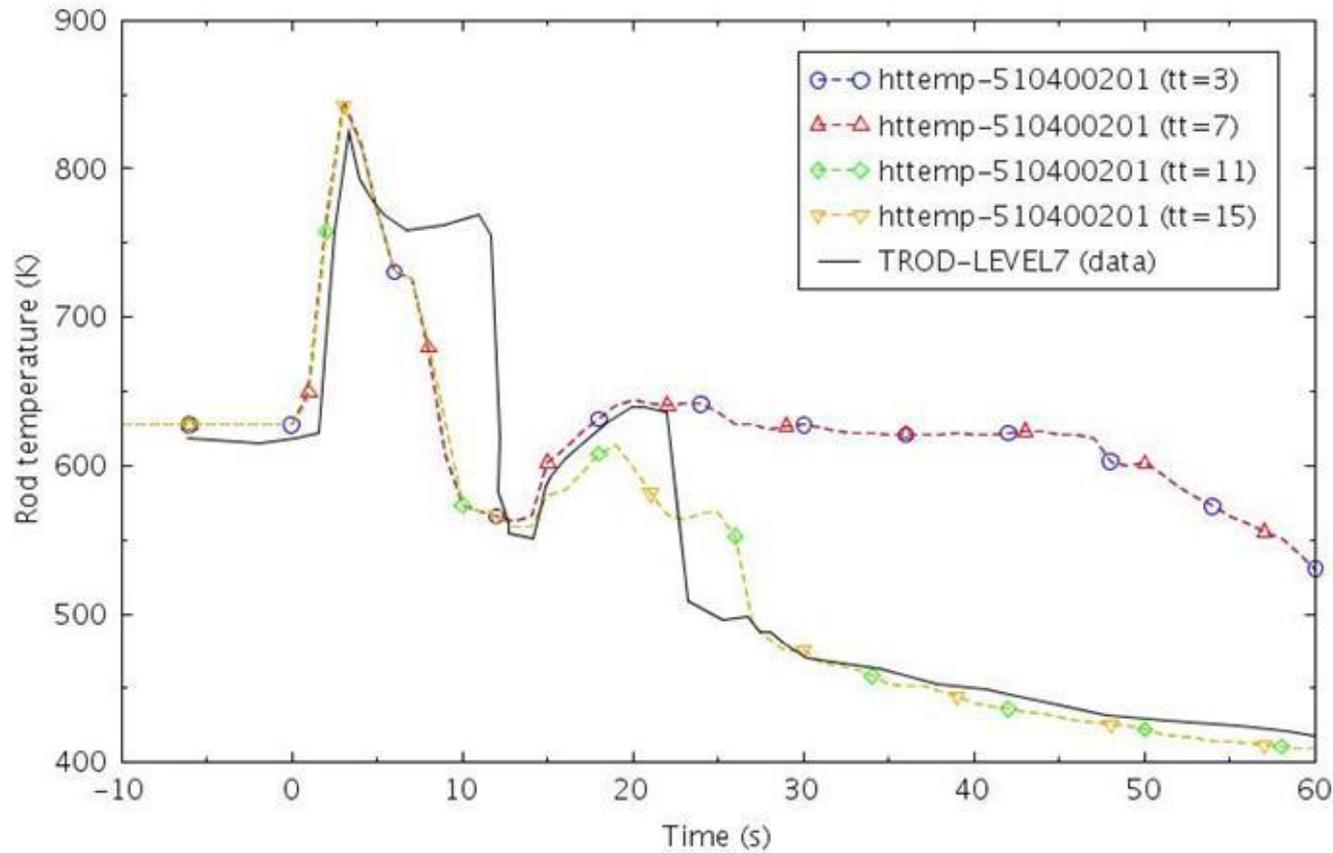
- Pressure distribution for the R-theta symmetric flow problem
- The nearly implicit scheme does not agree with theory at the inner boundary junction, but does agree with theory at the other junctions
- Results with the original and modified codes were similar
- Similar results have been seen in previous code versions

Results for DA Cases (LINUX)



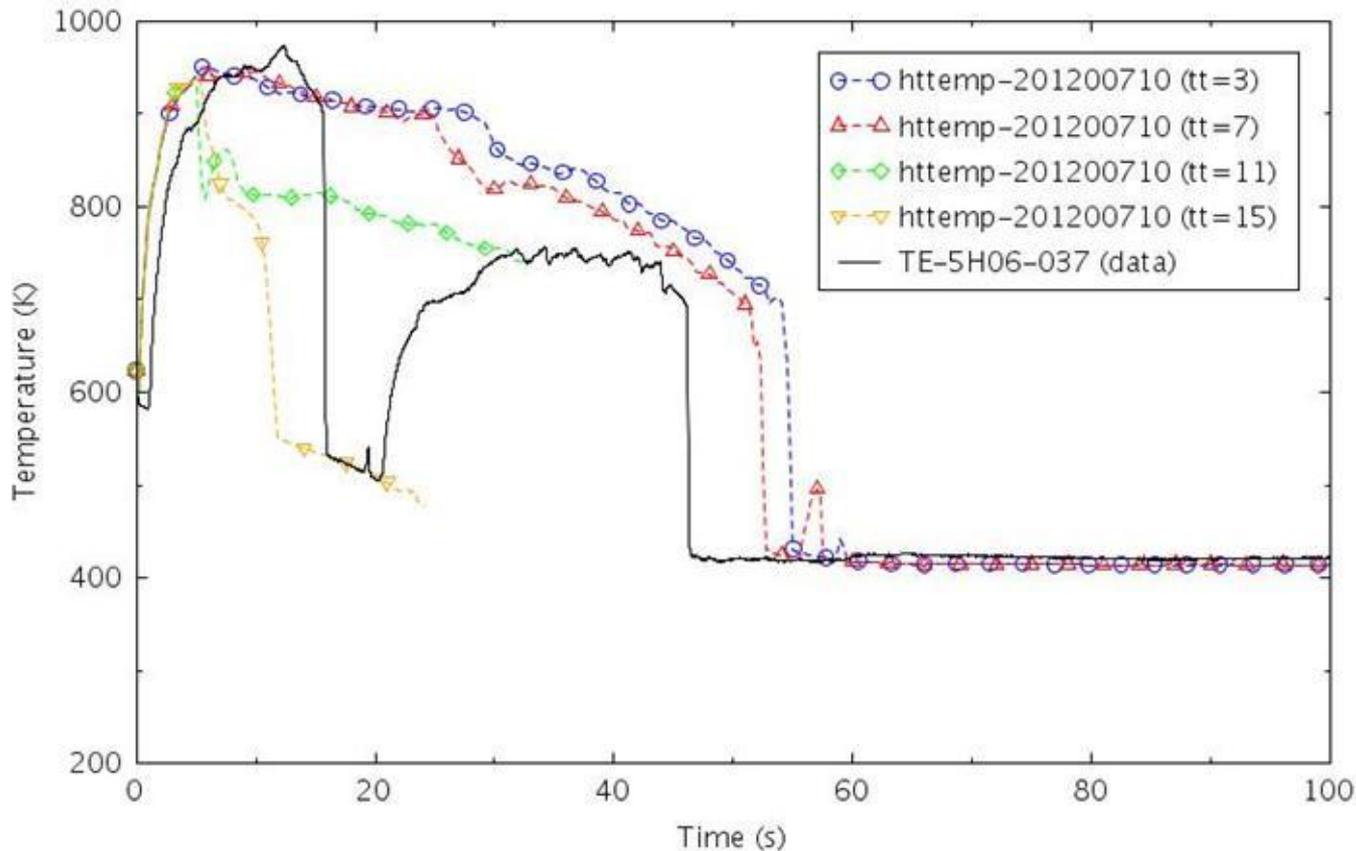
- Rod surface temperatures in FLECHT-SEASET Test 31504 at the 3.08m elevation
- The numerical option affects the quench time
- Similar results have been seen in previous code versions

Results for DA Cases (LINUX)



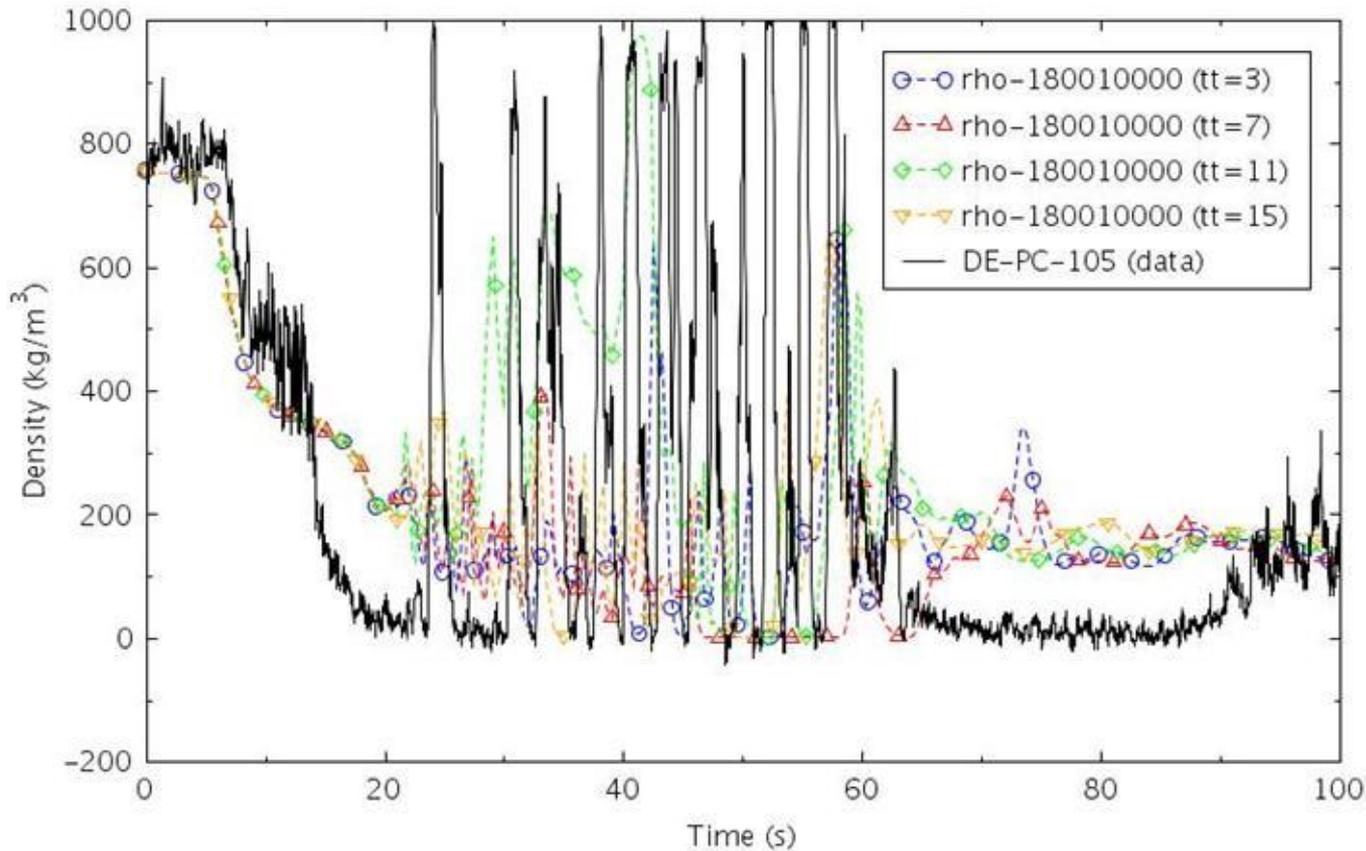
- Mid-core heater rod temperature for LOBI Test A1-04R
- The numerical option affects some cladding temperatures
- Similar results have been seen in previous code versions

Results for DA Cases (LINUX)



- Fuel cladding surface temperature at the 0.94-m elevation in LOFT Experiment L2-5 (3-D)
- The numerical option significantly affects some cladding temperatures
- Less variation occurred in 1-D calculations

Results for DA Cases (LINUX)



- Fluid density in the intact loop cold leg during LOFT Experiment L2-5 (1-D)
- The numerical option significantly loop fluid densities
- Numerical uncertainty is relatively large
- Similar results expected between code versions and due to changes in requested time step size

Results for DA Cases (Windows)

- The testing of time step options on the DA cases was repeated with the Windows operating system
- The base code for the Windows testing was RELAP5-3D Version 3.0.1.t instead of 3.0.2.t, which did not install on Windows systems at the INL at the time the analysis was performed
- The results with the Windows operating system were generally similar to those shown previously except that most of the 3-D problems failed
 - The failures with the semi-implicit scheme have been resolved

Summary of DA Results

- The results with the modified code were generally similar to those obtained previously
- The semi-implicit numerical scheme was more robust
 - Failures were more likely to occur when the nearly implicit numerical scheme was used
- The problems associated with the tt options were identified previously or corrected in subsequent code versions
- Relatively large numerical uncertainty was observed for
 - Loop fluid density during reflood
 - Quench times during reflood
 - Cladding temperatures at locations where rewets are likely, particularly near the top or bottom of the core

Conclusions

- The expanded verification testing showed that the downflow modifications had negligible or relatively small effects on most of the installation problems and DA cases
- Larger effects were seen for a few cases
 - These cases were judged to have higher numerical uncertainty that cause them to be relatively sensitive to minor code modifications, time steps, etc.
- Cases and time intervals with increased numerical uncertainty were identified
 - Loop fluid densities during reflood
 - Quench
 - Rewet
- The results were generally similar with the LINUX and Windows operating systems

Conclusions

- The expanded testing identified several errors or potential errors in the nearly implicit numerical scheme
 - Jet pump, turbine, and MULTID components
 - Supercritical applications
- Potential improvements in test cases were identified
 - Use of 107 card for supercritical water test problems
 - Add expanded minor edit cards for plotting results from the radio-nuclide model
 - Reduce oscillations in Semiscale Test S-NC-10 Part 3 or provide a more accurate measure of the average flow rate
- The methods developed can be easily used to test future code modifications and versions